Digital feedback stabilization of a single-axial-mode CO_2 TEA laser

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We have achieved long-term stability in producing high-power single-axial-mode CO_2 laser pulses with a hybrid oscillator (TEA laser + low-pressure section) by using a novel digital feedback system that electronically adjusts cavity length.

The problem of obtaining high-power single-axial-mode CO_2 laser pulses was first solved by the hybrid laser of DeTemple and Nurmikko.[1-3] Their solution consists of adding to a high-power TEA laser a low-pressure (<5 Torr) intracavity section which provides a small amount of additional gain only within its Doppler bandwidth (≈ 55 MHz). Since the $c/2L$ axial mode spacing in a typical hybrid resonator is approximately 60 MHz, much of the time only one axial mode will fit within the Doppler bandwidth, thereby experiencing larger gain and (via mode competition) ensuring single-axial-mode operation. Sometimes, however, the overall cavity spacing (which, of course, is subject to thermal drift) will be such that two axial modes just straddle the gain curve of the low-pressure section, resulting in dual-mode operation and a subsequent undesirable 60-MHz intensity modulation of the output pulse.

In this paper we describe a digital feedback system that monitors each laser pulse for any 60-MHz mode-beating and responds by changing the oscillator cavity length by an amount $\Delta L \simeq 2.7\ \mu$m, corresponding to a frequency shift of all modes of $\Delta \nu \simeq 32$ MHz. If two axial modes happen to straddle the Doppler-broadened gain curve, the cavity length is automatically shifted and single-axial-mode operation is accomplished.

The hybrid laser system used in our experiment is fairly conventional. Briefly, the TEA laser head is an atmospheric-pressure Tachisto Model 215 commercial unit, and the low-pressure section is a 145-cm-long, 2.5-cm-i.d. tube kept at 3.4 Torr. The low-pressure section is longitudinally pulse-discharged 120 μs before the TEA section fires, using an arrangement described by Loy.[4] The overall cavity is 244 cm long, is grating-tuned in the rear, and has a 10-m radius of curvature Ge output mirror.

Our testing arrangement is shown in Fig. 1. We diverted part of each pulse via a sodium chloride flat to a Ge : Au detector to monitor on an oscilloscope the pulse quality, while sending the main beam through attenuators to the MBD (mode-beating detector). In actual practice the MBD would be placed in the diverted arm of the beam; the MBD is sensitive enough (3.5 kW) that only a small fraction of each pulse need be diverted. The basic functions of the MBD are (1) to detect the light, (2) to filter, amplify, and rectify any 60-MHz modulation, and (3) to change the output state of a flip–flop should the rectified voltage become larger than a preset amount, thereby switching the voltage across a PZT (piezoelectric translator). The PZT changes the cavity length in response to the applied voltage, thus completing the feedback loop (see Fig. 2).

Depending on the exact cavity length, the laser pulses either sporadically mode beat, or never mode beat. Pulses with mode beating could be easily distinguished from those without for incident powers above 3.5 kW; below 3.5 kW discrimination is less reliable due to leakage of rf through the rectifier. On our Newport Research Optical Table, mode beating would drift in and out in roughly 20 min. Mode-beating detection was very positive, however, and any laser shot with more than 20% mode-beating ripple caused switching of the PZT volt-

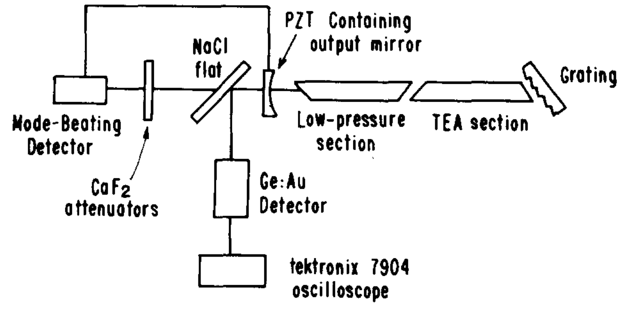

FIG. 1. Experimental arrangement. In response to 60-MHz mode beating in a pulse, the mode-beating detector switches the voltage across a PZT containing the cavity output mirror.

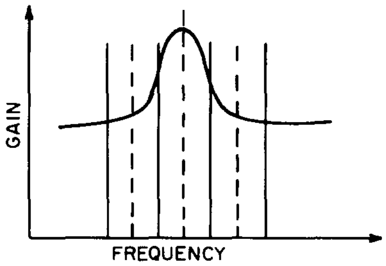

FIG. 2. The mode-beating detector changes the axial cavity mode frequencies from the solid lines which straddle the gain curve to the dashed lines which are centered on the gain curve.

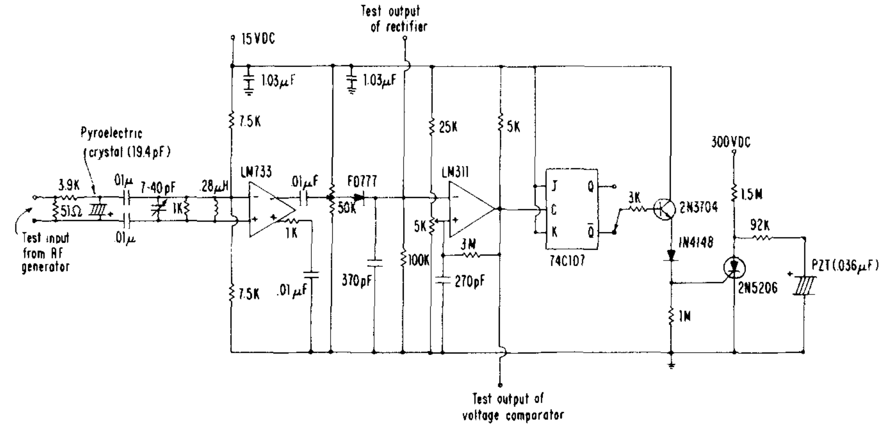

FIG. 3. Mode beating detector electronics. From left to right the major parts are: (1) pyroelectric crystal, (2) tuned RLC filter, (3) LM733 amplifier, (4) rectifier circuit, (5) LM311 voltage comparator, (6) 74C107 flip–flop, (7) 2N3704 emitter-follower buffer, (8) high-voltage switching SCR, (9) piezoelectric translator.

age. For the cavity drift rate and 1 pps repetition rate in our experiment, this implies only one partially multimode pulse per 1200.

In conclusion, single-axial-mode high-power CO_2 laser pulses can be guaranteed by the rather simple digital technique of changing cavity lengths by $\simeq\frac{1}{4}\lambda$ in response to mode beating.

The mode-beating detection circuitry is shown in Fig. 3. The laser beam is incident upon a pyroelectric detector (Molectron Model P1-11); the detector can be modelled as a light-intensity-proportional current source (1.25 μA/W) shunted by the crystal capacitance (19.4 pF). The current passes through a parallel RLC capacitance-tuned filter with a Q of about 10, ensuring that only intensity modulations near 60 MHz are passed (the filter cannot be too sharp, of course, because of the shortness of the laser pulse), after which it is amplified by a 733 IC Differential Video Amp with a small-signal gain of roughly 25. A simple rectifier filter then peak-detects the rf amplitude modulation and presents a relatively long-lived (37 μs) signal proportional to the mode-beating modulation to an LM311 Voltage Comparator whose trigger sensitivity is trimpot-controlled. Any change in the voltage comparator output state then flips the state of a CMOS 74C107 JK flip–flop. The flip–flop drives, via an emitter-follower buffer, the gate of a high-voltage 2N5206 SCR, causing the SCR to either short or hold off 300 V to a Lansing Model 21.934 piezoelectric translator in which the output mirror is held. This corresponds to a translation of 2.7 μm, or an axial-mode frequency shift of 32 MHz. For testing convenience a manual switch can also switch the high-voltage SCR's states, and provision is made for an rf generator to drive the input filter through 3.9 kΩ.

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[1] T. DeTemple and A. Nurmikko, Opt. Commun. **4**, 231 (1971).

[2] A. Gondhalekar, E. Holzhauer, and N. R. Heckenberg, Phys. Lett. A **46**, 229 (1973).

[3] A. Gondhalekar, N. R. Heckenberg, and E. Holzhauer, IEEE J. Quantum Electron. **QE-11**, 103 (1975).

[4] M. M. T. Loy and P. A. Roland, Rev. Sci. Instrum. **48**, 554 (1977).

Precision axial translator with high stability

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We describe a new type of translator which is inherently stable against torsion and twisting. This concentric translator is also ideally suited for precise axial motion with clearance of the center line.

In conventional designs of translation devices the driving and guiding parts are functionally separated. This can reduce the stability and precision for long movements along a center line under load conditions, especially as flexing and twisting are difficult to suppress for free-standing translation stages.

We describe here a simple axial translator which is superior over conventional designs for many applications. By integrating and redesigning the separate basic parts of a translation device we arrive at the metering axial translator (MAT) shown in Fig. 1. The underlying principle is rather simple but quite effective. The MAT con-